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Macro-site selection of wind/solar hybrid power station based on ELECTRE-II

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ABSTRACT

Currently, many defects have appeared in wind and solar power generation systems. Utilizing the complementary of wind and solar power generation will break the bottleneck of new energy development. How to select the site of wind/solar hybrid power station scientifically is a primary problem. First, the framework of the indicator system is obtained from the literature review and refined according to the resources evaluation standards and different perspectives of the various scholars. Then this paper selects seven wind/solar hybrid power stations which have been put into operation as the case study, weights the indicators through the method of order relations, and evaluates these seven regions via ELECTRE-II. The conclusions are consistent with the related research findings and have better correctness, proving the feasibility and effectiveness of the method. It may provide some theoretical basis for the macro-site selection of wind/solar hybrid power station.

Contents

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1. Introduction

With the gradual development of low carbon economy, the renewable energy power generation in China, especially some clean and renewable energy resources industries such as wind and solar power generation, is developing rapidly. However, there are many defects such as unstable energy supply in wind power. The generated electricity of photovoltaic station in the daytime is more than that in the night because the solar radiation changes. But the form of wind power generation is just the opposite. The wind speed is low in the daytime with small power output and high in the night with large power output. Moreover, these two kinds of renewable energy and electricity production resources are influenced by the climate greatly. And the large storage technologies that can store the renewable electricity have not yet been developed.

Large scale of independent wind power generation lacks stability, and solar power generation could not generate electricity continuously day and night. However, these two kinds of electricity are mutually complementary. If these two kinds of energy can make up their defects for each other, the generated electricity can be more continuous and stable. As early as 1981, Busch and Kellenbach, the engineers of Denmark, put forward the concept of a solar/wind power system and presented a simple system with the wind turbines and photovoltaic components [1]. The solar and wind power system is also called a PV/wind hybrid power system.

The site selection of the PV/wind hybrid power system is another complex decision-making problem that needs us to consider many factors such as the wind and solar energy resources, the grid construction cost, the distance to load center, the economic and social factors, all of which can affect the economy of projects and may threat the safe and stable operation of the grid. Therefore, study on scientific site selection methods is becoming a significant issue of the construction of the hybrid system. In this paper, more closely related indicators of wind power and photovoltaic site selection are excluded based on the former researches, which makes the indicator system more comprehensive and more reasonable. In order to weight the indicators, this paper uses the method of order relations that can reflect the subjective preferences of the decision-makers. And in the comprehensive evaluation methods, it uses an ELECTRE-II method that has a clear sequencing logic. Thus, the results are reliable, which provides reference for the decision-makers in practice.

2. Literature review

Validated research results on the site selection of the wind/solar hybrid power system are very rare. Independent renewable energy stations have been researched by some scholars. The researches mainly focus on two aspects: the establishment of an indicator system and a comprehensive evaluation method. In terms of the former, Yoreley analyzed some site selection parameters influencing the operational effects [2]. The feasibility analysis of wind station in Yueyang was done after experimenting with dozens of wind resource measuring sites by Hang et al. [3]. Li Zhengran and Hong Zulan had eight identified groups of evaluation factors from experiment and delineated seven kinds of sites, which are suitable for developing wind farms [4]. In terms of the latter, Amy et al. studied the site selection method of wind farms using the Analytic Hierarchy Process method [5]. Rob et al. researched the site selection of wind farm using Spatial Multi-criteria Analysis [6,7]. Lack of wind data, an approach to calculate wind resource parameters accurately and fleetly, was proposed by Qian and Cui [8]. Some scholars summed up the PV power plant selection process and did some case studies [9,10]. But, the research of site selection of the PV/wind hybrid power system is seriously deficient.

The theories and calculation methods of site selection include the Grey Clustering Method, the Fuzzy Comprehensive Judgment Method, the Analytic Hierarchy Process [11], Ideal Matter–Element Model [12] and Expert System [13].

In all, the PV/wind hybrid power system has great development potential all over the world, but to develop the large-capacity hybrid system, the site selection of PV/wind hybrid power station is a big problem. The issue of site selection of the hybrid power plants is researched sparsely. Therefore, this paper focuses on the macro-site selection of PV/wind hybrid power station with establishing a comprehensive evaluation system and determining the indicator weights. The research results might provide a scientific decision-making method for site selection of PV/wind hybrid power station.

3. Research steps

STEP 1: Describe the site selection problem and define the evaluation object.
STEP 2: Collect the related evaluation indicators and refine the indicator system based on evaluation standards and expert opinions.
STEP 3: Collect the data of the indicators of the evaluated regions which are selected as the site of wind/solar hybrid power stations, process the data and use the method of ELECTRE-II to evaluate the regions.
STEP 4: Analyze the results and verify the validity and advantages of the evaluation method.
STEP 5: Conclusions.

4. Macro-site selection indicators

4.1. Definition

The site selection of hybrid power station is a complex problem which is often divided into two stages: macro-site selection and micro-site selection. The macro-site selection refers to choosing the most valuable small region through considering the natural resources, grid connection, traffic, geo-graphical, environment, social and economic conditions of vast areas. The results of macro-site selection can provide an important basis for project construction

and micro-site selection decision [14]. In addition, the micro-site selection refers to determining the layout of power unit through the techno-economic comparison based on the macro-site selection conclusions [15].

4.2. Indicator designing based on literature statistics

A literature is the crystallization of knowledge of the experts. We tried to find out all the important factors that can reflect the merits of site selection through literature statistics and then obtain a more complete indicator system. However, redundant indicators are easily introduced. Therefore, the relevant technical specifications and expert opinions should be taken into consideration. Based on this, some similar indicators are reduced and all the selected indicators are classified reasonably.

Statistic data on wind or solar power generation site selection from 19 pieces of literatures is analyzed. Then an indicator system is extracted and recognized by experts, which includes natural resources, traffic conditions, economic factors, environmental factors, social factors, geo-graphical conditions and technical factors (as shown in Table 1). Also it has 32 s-class indicators. These indicators include macro- and micro-factors. When discussing the macrosite selection, we need to assume that we will use the same power equipments. Therefore, the microfactors are not our focus in this paper, such as the Technical Factors, which should be considered in a microsite selection method. Meanwhile, there is redundant information because of various research perspectives from different scholars. So some indices are streamlined based on some national standards and industrial standards (GB/T 18710-2002 and QX/T 89-2008).

4.3. Indicator refinement

The framework of the indicator system could be obtained from the literature review. But due to the different perspectives of various scholars and the relevance of the indicators, it is necessary to refine the indicators. Principle of reduction and collection refers to deleting or combining indicators that can be deduced each other or have a relatively strong correlation.

4.3.1. Natural resources

4.3.1.1. Wind energy resources assessment. According to GB/T 18710-2002, the main reference indicators of the wind resource assessments include wind power density, wind direction frequency, wind speed and turbulence intensity.

4.3.1.1.1. Wind power density. Including the effect of wind speed and wind speed distribution on the air density, wind power density is a composite indicator to evaluate the wind energy resources. The calculation formula of wind power density is

$$D_{wp} = \frac{1}{2}\sum_{i=1}^{n}(\rho)(v_i^3) \tag{1}$$

In the above formula, n refers to the records number in a set period. ρ represents the air density (kg/m^3). v_i^3 stands for the cubic meters of wind speed (m/s) in the ith record.

Wind power density is shown in Table 2. The values of wind speed at different heights are calculated based on the annual average wind speed and the wind shear index (1/7). Now the hub height of mainstream large-scale onshore wind turbines is generally more than 50 m, so the wind power density value at 50 m is selected as the evaluation indicator.

4.3.1.1.2. Wind frequency and wind direction (wind direction condition). The arrangement of the generator sets location in wind farms depends on the distribution of wind power density direction and topographical features. In wind rose diagram, a predominant wind direction or two opposite wind directions should be selected. The best effects would be obtained if the main wind direction is vertical to the mountain ridge. This is a qualitative indicator which could use the integers from 1 to 5 as the value of different quantitative ranks.

4.3.1.1.3. Turbulence intensity. The formula of turbulence intensity is as follows:

$$I_T = \frac{\sigma}{V} \tag{2}$$

In the above formula, σ stands for the standard deviations of wind speed (m/s) and V stands for the average wind speed (m/s). If the value of I_T is below 0.10, the turbulence intensity is relatively small. If the value of I_T is between 0.10 and 0.25, the turbulence intensity is medium. If the value of I_T is more than 0.25, the

Table 1
Literature statistics.

Description	Frequency	Description	Frequency
1. Natural resources		**4. Environmental factors**	
Power density	3	Pneumatic pollution	1
Wind direction	7	Noise pollution	2
Wind speed and speed change	10	Light pollution	3
Turbulence intensity	5	Energy saving	1
Effective wind hours (mean yearly)	3	Pollutant reduction	1
Gross solar radiation	4	**5. Social factors**	
Six hours sunshine days/month	2	Local residents attitude	1
Sunshine days	1	Distance to load center	1
Solar energy variation characteristics	1	**6. Geo-graphical conditions**	
2. Traffic conditions		Geological/topographic condition	7
Traffic convenience degree	3	Land usage condition	4
Means of transportation	1	**7. Technical factors**	
Transmission line length	4	Rated power	3
3. Economic factors		Cut-in/cut-out wind speed	1
Total investment	4	Wake loss effect	2
Interest incurred during construction	1	Equipment producing area	2
Total project payback period	2	Energy conversion efficiency	2
Operation and maintenance costs	2		
ROI (return on investment)	1		
Investment profit rate	1		

Table 2
Wind power density level.

Level	10 m		30 m		50 m		Grid connected generation
	Wind power density (W/m^2)	Average wind speed (m/s)	Wind power density (W/m^2)	Average wind speed (m/s)	Wind power density (W/m^2)	Average wind speed (m/s)	
1	< 100	4.4	< 160	5.1	< 200	5.6	Poor
2	100–150	5.1	160–240	5.9	200–300	6.4	Poor
3	150–200	5.6	240–320	6.5	300–400	7.0	Normal
4	200–250	6.0	320–400	7.0	400–500	7.5	Good
5	250–300	6.4	400–480	7.4	500–600	8.0	Very good
6	300–400	7.0	480–640	8.2	600–800	8.8	Very good
7	400–1000	9.4	640–1600	11.0	800–2000	11.9	Very good

turbulence intensity is too strong. Turbulence characteristics of wind farms are very important, which may have an adverse effect on wind turbine performance, such as reducing power output and leading to extreme loads, and eventually undercutting and destroying wind power generators.

4.3.1.2. Solar energy resource evaluation. The evaluation method for solar energy resources (QX/T 89-2008) in the weather industry standard of China states that the solar resource could be evaluated from the richness and stability levels, which are reflected through the following two indicators respectively.

4.3.1.2.1. Annual amount of solar radiation. Total solar radiation is the sum of the direct solar radiation and the diffuse radiation (MJ/m^2). The formulas are as follows. First, daily amount of solar radiation needs to be calculated:

$$Q_n = \frac{TI_0}{\pi\rho^2}(\omega_0 \sin\varphi \sin\delta + \cos\varphi \cos\delta \sin\omega_0) \tag{3}$$

where T is the time period (units: $24 \times 60\ \text{min} \cdot \text{d-1}$), I_0 is the solar constant 0.0820 (units: MJ/(M^2 min)), ρ is the distance factor between the sun and the earth (units: dimensionless), φ is the geographic latitude (units: RAD), δ is solar declination (units: RAD), ω_0 is the hour angle between sunrise and sunset (units: RAD).

Monthly amount of solar radiation:

$$Q_m = \sum_{d=1}^{M} Q_d \tag{4}$$

Annual amount of solar radiation:

$$Q_Y = \sum_{M=1}^{12} Q_M \tag{5}$$

The evaluation level of solar radiation is shown in Table 3.

4.3.1.2.2. The stability level of solar energy resources. The stability level of solar energy resources could be measured by the ratio of the maximum number to the maximum number of days whose sunshine duration is greater than 6 h in 12 months of a year. k is a dimensionless quantity. The formula is as follows:

$$K = \frac{\max(\text{Day1}, \text{Day2}, \ldots \text{Day12})}{\min(\text{Day1}, \text{Day2}, \ldots \text{Day12})} \tag{6}$$

4.3.2. Economic factors

Economic factors reflect the costs of power plant construction and operation as well as their economic profitability, mainly including the indicators of local power demand, the construction cost and the operation and maintenance cost of the project.

Table 3
Solar radiation level (year).

Annual amount of solar radiation(MJ/(m^2))	**The richness level**
6300	Great
5040–6300	Better
3780–5040	Good
3780	Common

4.3.2.1. Electricity demand. The necessity of power plants construction is decided by electricity demand which depends on the degree of regional economic prosperity. The greater the electricity demand, the more necessary the construction of power plants. On the contrary, when the demand is small, the generated electricity should be transported to the areas which need power by the long-distance transmission system. As it is difficult to obtain the data statistics of electricity demand in sample sites, electricity demand will be estimated through GDP.

4.3.2.2. Construction cost. Construction cost refers to the total expense in the construction process of the power station. It is not just an economic indicator, but also could reflect the technological and environmental factors such as geological/topographic condition and land usage condition under geo-graphical conditions. For example, when the topography and land usage are in bad conditions, more funds would be input to the construction. Therefore, topographic and geologic conditions indicators will be omitted, and reflected in the construction cost.

4.3.2.3. Operation and maintenance cost. Different regions and environments have a greater impact on the equipment operation and maintenance. Therefore this kind of factors could be reflected through the indicator of operation and maintenance cost.

4.3.3. Traffic conditions

Traffic conditions reflect the complexity of transport during the process of construction as well as operation and maintenance, including traffic convenience degree and transmission line length.

4.3.3.1. Traffic convenience degree. Traffic convenience degree reflects the complexity of transportation to the site, such as workers, materials, equipments in the course of construction, operation and maintenance.

4.3.3.2. Transmission line length. The longer the length of transmission lines, the further the distance from the power plant to the load center or network. And more resources would be needed to put into the line construction. For that the indicator of transmission line

length could reflect the distance from the power plant to the load center; the load center distance indicator is removed and substituted for transmission line length.

4.3.4. Environmental factors

Renewable energy power plants have an advantage over traditional thermal power plants in terms of the environment. And environmental factors are the basic start point of the world to promote the development of new energy, which consist of two major indicators. One is the pollution and destruction of the environment during the construction; the other is the effects of energy-saving and pollutant reduction during the project operation.

4.3.4.1. Pollution. Pollution refers to the ecological damage during the construction. In China, new energy projects are developed faster in western regions where the ecological environments are fragile. Without effective environmental protection measures, the construction of the projects would have irreversible effects on the local ecology.

4.3.4.2. Energy saving/pollutant reduction. The indicator of energy-saving and pollutant reduction refers to the positive effects on the environment during the project operation. It is an important evaluation factor and the main competitive advantage compared to conventional thermal power.

4.3.5. Social factors

Social factors are important factors in construction projects of China, which reflect the people's views on the project. Negative public opinions can result in resistance of the project implementation and the realization of economic and environmental benefits. Therefore, project decisions should take the public opinions into consideration. The indicator of local residents' attitude reflects social factors.

Based on the above analysis, the indicator system could get refined, as shown in the Table 4. This system can evaluate the macro-site selection of wind/solar hybrid power station more effectively.

5. The comprehensive evaluation methods (ELECTRE-II)

As to traditional evaluation methods, policy makers would wonder whether the selection of the comprehensive evaluation method and the weight determination method is scientific. And generally the results of the evaluation methods are only to be a secondary reference for decision makers. Policy makers could not rely too heavily on these evaluation methods, which may limit the application of comprehensive evaluation methods. The ELECTRE-II method applies the concept of outranking relationship. If there is no obvious merit between Plan A and Plan B, the decision-makers assume that A is better than B at a certain degree of risk. Then through a series of evaluation of outranking relations, the inferior plan would be identified. Compared with other comprehensive evaluation methods, the degree of risk is clear for the decision-makers. Therefore, the ELECTRE-II method can not only reflect the actual merits, but provides the decision-makers with more convincing results in practice. ELECTRE (Elimination et Choice Translating Reality) was first proposed by a Frenchman called Roy in 1971. It is intelligible and could bear the responsibility for decision-making in the evaluation process. What is more, the process of the calculation is not complicated and difficult to understand, and very easy to program. It just requires that policy makers set the weights, α and d_j based on the data and features, and the results would be worked out programmatically.

Table 4
Streamlined indices.

First class indicators	Second class indicators	Description
Natural resources	Wind power density	Kinetic energy generated by the air (W/m^2)
	Wind direction condition	Stability of wind direction
	Turbulence intensity	Ratio of deviation standard wind speed and average wind speed
	Gross solar radiation	Accumulative value of solar radiation intensity (MJ/m^2)
	Sunshine stabilization rate	Ratio of the maximum to minimum of sunshine days (> 6 h)
Economic factors	Electricity demand	Gross demand of electricity in a certain range (MW)
	Construction cost	Construction cost of the hybrid plant (RMB/Kw)
	Operation and maintenance cost	Operation and maintenance cost of the hybrid plant (RMB/Kw)
Traffic conditions	Traffic convenience degree	Convenience degree using traffic mean to the plant
	Transmission line length	Electricity transmission distances (km)
Environmental factors	Pollution	Pollution degree during the construction period
	Energy saving/pollutant reduction	Energy saving/pollutant reduction as the clean electricity
Social factors	Local residents attitude	The attitude of the local residents for the plant

Table 5
Original data.

Indicator Program	X1 Max	X2 Max	X3 Min	X4 Max	X5 Max	X6 Max	X7 Min	X8 Min	X9 Max	X10 Min	X11 Min	X12 Max	X13 Max
P1	532.6	3	0.1067	5624.4	1.26	470	45,000	0.18	5	30	3	2	5
P2	446	5	0.1146	6012.4	1.61	720	30,000	0.15	6	200	3	3	5
P3	288.2	4	0.1465	6005.2	1.59	200	29,794	0.15	4	75	4	5	4
P4	359.8	4	0.11	6196.6	1.7	512	11,557	0.15	4	15	4	5	5
P5	427.5	5	0.091	6117.3	1.56	0	20,353	0.15	4	50	4	4	4
P6	285.1	3	0.2	6493	1.41	233	11,550	0.15	2	50	4	2	5
P7	189.3	2	0.2	5800	2.05	188.6	11,543	0.15	2	80	5	2	4

5.1. Outranking relation

The ELECTRE-II method is a method to solve problems of multiple attribute decision making. General means to resolve similar problems is to establish a complete orderings based on the set of viable programs. However, the idea of ELECTRE is to explore a weaker order relation, which is called Outranking Relation.

Outranking Relation is that in a set of programs X $(x_i, x_k \in X)$ which is given the order of preference and attribute matrix $(\{y_{ij}\})$ by decision makers, if decision makers believe$x_i \geq x_k$, it is said that the level of x_i is higher than x_j, recorded as $x_i o x_k$. And decision makers should be able or willing to bear the risks arising out of the judgment.

Equal Ranking Relation means that in a set of programs X $(x_i, x_k \in X)$, if and only if the scenario in which $U_1, U_2, \cdots U_r$, $V_1, V_2, \cdots V_r$, $r \geq 1, s \geq 1$ brings $x_i o x_k$ (or $x_i oU_1, U_1 oU_2, \cdots, U_r oU_k$) and $x_k o x_i$ (or $x_k oV_1, V_1 oV_2, \cdots, V_r oV_k$) into existence, it is said that the level of x_i is the same with x_k, recorded as $x_i I_r x_k$. The characters of Outranking Relation are as follows:

(1) Weak transitivity. ① If $x_i o x_0$ and $y(x_0) \geq y(x_k)$, then $x_i o x_k$. ② Or if $y(x_i) \geq y(x_0)$ and $x_0 o x_k$, then $x_i o x_k$.
(2) Reflexivity. It is obvious that xox and $xI_r x$ are both reasonable.
(3) Symmetry.
(4) Incomparability of situations.

5.2. Concordance test and non-concordance test

In order to judge whether there exists Outranking Relation, it is necessary to carry out concordance test and non-concordance test. The steps are as follows:

(1) The weight of every property should be set by decision makers, $w = (w_1, w_2, \ldots, w_n)$.
(2) Concordance test. It is set that the larger the value of every property $(y_j (j = 1, 2, 3, \ldots, n))$, the better the situation.

5.2.1. Classification of property order number

Depending on the property j, if x_i is better than x_k, it would be recorded as $y(x_i) > y(x_k)$. The set of all properties j which meet the condition $y(x_i) > y(x_k)$would be recorded as

$$J^+(x_i, x_k) = \{j \mid 1 \leq j \leq n, y_j(x_i) > y_j(x_k)\} \tag{7}$$

Similarly, the formula of $J^=(x_i, x_k)$ and $J^-(x_i, x_k)$ is as follows:

$$J^=(x_i, x_k) = \{j \mid 1 \leq j \leq n, y_j(x_i) = y_j(x_k)\} \tag{8}$$

$$J^-(x_i, x_k) = \{j \mid 1 \leq j \leq n, y_j(x_i) < y_j(x_k)\} \tag{9}$$

5.2.2. Calculation of concordance test index

Concordance index I_{ik} is defined as a ratio of the sum of these properties' (in which x_i is not inferior to x_k) weights to the sum of all the properties' weights. The formula is as follows:

$$I_{ik} = \frac{\sum_{j \in J^+(x_i, x_k)} w_j + \sum_{j \in J^=(x_i, x_k)} w_j}{\sum_{j=1}^{n} w_j} \tag{10}$$

Concordance index I'_{ik} is defined as a ratio of the sum of those properties' (in which x_i is better than x_k) weights to the sum of all the properties' (in which x_i is inferior to x_k) weights. The formula is as follows:

$$I'_{ik} = \frac{\sum_{j \in J^+(x_i, x_k)} w_j}{\sum_{j \in J^-(x_i, x_k)} w_j} \tag{11}$$

Set $0.5 \leq \alpha \leq 1$, if $\hat{I}_{ik} \geq 1, I_{ik} \geq \alpha$, then it passes the concordance test.

5.2.3. Calculation of non-concordance test index

The threshold of each property should be set by decision makers. For any j, if $y_j(x_k) - y_j(x_i) \geq d_j$, then no matter how large the values of the other properties are, it could not accept the compensation for other properties, namely $x_i o x_k$ is no longer recognized.

5.2.4. Definition of Outranking Relation

For each pair of programs x_i and x_k in the program set, if $I_{ik}' \geq 1, I_{ik} \geq \alpha$, and for each j, $y_j(x_k) - y_j(x_i) < d_j$ exists, then $x_i o x_k$ is recognized. Actually, non-concordance test is a special type of majority voting rule using the weights of properties.

5.3. The Steps of ELECTRE-II

Roy and some other scholars proposed ELECTRE-II based on ELECTRE-I. The calculation procedure of ELECTRE-II is as follows:

Step 1: Determine three thresholds (high, medium and low,) respectively called α^*, α^0, α^-, and $0 < \alpha^- < \alpha^0 < \alpha^* < 1$.
Step 2: Determine two values of d, and $d_j^0 < d_j^*$. And define three dissonant sets as follows:

$$D_j^h = \{(y_{ij}, y_{kj}) \mid y_{kj} - y_{ij} \geq d_j^*, .i, k = 1, \ldots, m, i \neq k\} \tag{12}$$

$$D_j^m = \{(y_{ij}, y_{kj}) \mid d_j^* \geq y_{kj} - y_{ij} \geq d_j^0, .i, k = 1, \ldots, m, i \neq k\} \tag{13}$$

$$D_j^l = \{(y_{ij}, y_{kj}) \mid y_{kj} - y_{ij} \geq d_j^0, .i, k = 1, \ldots, m, i \neq k\} \tag{14}$$

Step 3: Define strong Outranking Relation (O_s) and weak Outranking Relation (O_w), respectively as follows:

$$X_i o_s X_k \Leftrightarrow \begin{cases} I_{ik}' \geq 1 & \text{and} \\ I_{ik} \geq \alpha^* & \text{and } (y_{ij}, y_{kj}) \in D_j^m (\text{all } j) \\ \text{or } \; I_{ik} \geq \alpha^0 & \text{and } (y_{ij}, y_{kj}) \in D_j^1 (\text{all } j) \end{cases} \tag{15}$$

$$X_i o_w X_k \Leftrightarrow \begin{cases} I_{ik}' \geq 1 & \text{and} \\ I_{ik} \geq \alpha^* & \text{and } \; y_{ij} - y_{kj} < d_j^0 (\text{all } j) \\ \text{or } \; I_{ik} \geq \alpha^0 & \text{and } \; y_{ij} - y_{kj} < d_j^- (\text{all } j) \end{cases} \tag{16}$$

Step 4: Construct points-to graphs. Construct a strong points-to graph based on the strong Outranking Relation O_s, and construct a weak points-to graph based on the weak Outranking Relation O_w.
Step 5: Sequence all programs according to the points-to graphs. It contains a positive sorting and a negative sorting.

(1) Positive sorting
The programs which have no front branches in the points-to graphs are called non-inferiority programs. The set of non-inferiority programs in the strong points-to graph is recorded as G, and the set of non-inferiority programs in the weak points-to graph is recorded as G_w. Select the intersection of G_s and G_w, record it as $C = G_s \cap G_w$, and then sequence them. The procedures are as follows:
1) Make $G_s^1 = G_s$ and $G_w^1 = G_w$.
2) Find two sets of non-inferiority programs G_s^1 and G_w^1, and determine the intersection C^1.
3) Delete the programs of intersection C^1 and all the front branches from these programs in the strong points-to graph and the weak points-to graph. Remaining strong graph and weak graph are respectively recorded as G_s^2 and G_w^2. Then determine the intersection of G_s^2 and G_w^2, called C^2.

4) Delete the programs of intersection C^2 and all the front branches from these programs in remaining strong points-to graph and weak points-to graph.
5) Repeat these steps above, obtain G_s^{k+1}, G_w^{k+1} and C^{k+1} until the intersection is an empty set.
6) Calculate the sorting value $V'(X_i)$ of every program. If a program belongs to the C^r set, then the value of this program is equal to r.

(2) Negative sorting
Reverse all the arrow directions in the strong points-to graph and the weak points-to graph, and a sort of mirror of positive sorting which is called negative sorting would be gained. According to the principle of positive sorting, the negative sorting value $V^0(X_i)$ of every program can be obtained. The smaller the value of $V^0(X_i)$, the lower the level of the program.

Step 6: Calculate the average sorting value of every program. Make $V'(p_i)$ $V^*(x_i)=\max_{x_i \in X} V^0(x_i)$ and $V''(x_i)=1+V^*(x_i)-V^0(x_i)$, then the average sorting would be obtained from the formula as follows:

$$\overline{V}(x_i)=\frac{V'(x_i)+V''(x_i)}{2} \tag{17}$$

Finally, the sequence can be arranged for every program according to the average sorting value.

6. Case analysis

6.1. Data preparation and processing

A case will be studied in order to elucidate the ELECTRE method and verify the validity of this method in macro-site selection of wind/solar hybrid power station. First of all, the indicator data (until June 2013) of seven wind/solar hybrid power stations which have been put into operation, distributed in various parts of China with good conditions of wind and solar energy was collected. This paper analyzes the conditions of these wind/solar hybrid power stations in the seven regions through the ELECTRE method, so as to show the advantage of this method applied in macro-site selection.

6.1.1. Original data

For the ease of calculation, 13 indicators (wind power density, wind direction condition, turbulence intensity, gross solar radiation, sunshine stabilization rate, electricity demand, construction cost, operation and maintenance cost, traffic convenience degree, transmission line length, pollution, energy saving/pollutant reduction, local residents attitude) are recorded as X_1, X_2, X_3, X_4, X_5, X_6, X_7, X_8, X_9, X_{10}, X_{11}, X_{12}, and X_{13}. Seven regions (Shantou, Zhangjiakou, Youyu, Erenhot, Yumen, Haixi Prefecture in Qinghai province, Naqu in Tibet) are recorded as P1, P2, P3, P4, P5, P6 and P7. The data of the 11 indicators in those selected regions is shown in Table 5.

Table 6
Data consistency of the indicators.

Quality	Max	Max	Min	Max	Max	Max	Min	Min	Max	Min	Min	Max	Max
Program/indicator	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13
P1	532.6	3	0.0933	5624.4	1.26	470	0	0	5	170	2	2	5
P2	446	5	0.0854	6012.4	1.61	720	15,000	0.03	6	0	2	3	5
P3	288.2	4	0.0535	6005.2	1.59	200	15,206	0.03	4	125	1	5	4
P4	359.8	4	0.09	6196.6	1.7	512	33,443	0.03	4	185	1	5	5
P5	427.5	5	0.109	6117.3	1.56	0	24,647	0.03	4	150	1	4	4
P6	285.1	3	0	6493	1.41	233	33,450	0.03	2	150	1	2	5
P7	189.3	2	0	5800	2.05	188.6	33,457	0.03	2	120	0	2	4

Table 7
The comparison of different dimensionless methods.

Methods	**Monotony**	**Differential invariance**	**Pan-neutral**	**Black scale-neutral**	**Interval stability**	**Volume constancy**
Standardization	Y	Y	Y	Y	N	Y
Extremum treatment	Y	Y	Y	Y	Y	N
Linear scale (minimum)	Y	Y	N	Y	N	N
Linear scale (maximum)	Y	Y	N	Y	N	N
Linear scale (mean)	Y	Y	N	Y	N	Y
Normalization processing	Y	Y	N	Y	N	Y
Vector norm	Y	Y	N	Y	N	N
Efficiency coefficient	Y	Y	Y	Y	Y	N

Table 8
The dimensionless date of the extremum treatment method.

Program/indicator	**X1**	**X2**	**X3**	**X4**	**X5**	**X6**	**X7**	**X8**	**X9**	**X10**	**X11**	**X12**	**X13**
P1	1.000	0.333	0.856	0.000	0.000	0.653	0.000	0.000	0.750	0.919	1.000	0.000	1.000
P2	0.748	1.000	0.783	0.447	0.443	1.000	0.448	1.000	1.000	0.000	1.000	0.333	1.000
P3	0.288	0.667	0.491	0.438	0.418	0.278	0.454	1.000	0.500	0.676	0.500	1.000	0.000
P4	0.497	0.667	0.826	0.659	0.557	0.711	1.000	1.000	0.500	1.000	0.500	1.000	1.000
P5	0.694	1.000	1.000	0.568	0.380	0.000	0.737	1.000	0.500	0.811	0.500	0.667	0.000
P6	0.279	0.333	0.000	1.000	0.190	0.324	1.000	1.000	0.000	0.811	0.500	0.000	1.000
P7	0.000	0.000	0.000	0.202	1.000	0.262	1.000	1.000	0.000	0.649	0.000	0.000	0.000

Some indicators are positively related to the integrated evaluation indicator, while some are negatively related. For example, wind power density, wind direction condition,, gross solar radiation, sunshine stabilization rate, electricity demand, traffic convenience degree, energy saving/pollutant reduction and local residents attitude belong to the former, and turbulence intensity, construction cost, operation and maintenance cost, transmission line length and pollution belong to the latter. Therefore, the indicator system should achieve data consistency by some treatment which could make negative correlation indicators converted to positive correlation indicators. The formula is as follows. The date of quantitative indicators could be quantified by the experts through the scoring method. And the consistent date is as shown in Table 6.

$$x' = M - x \tag{18}$$

6.1.2. Non-dimension of the date

As the difference in dimension among various indicators is the main factor affecting the result of the overall evaluation, the indicators need to be dimensionless. An ideal dimensionless method has the following characteristics: ① Monotony, ② Differential invariance, ③ Pan-neutral, ④ Black scale-neutral, ⑤ Interval stability, and ⑥ Volume constancy. In reality, the dimensionless method which could meet the above six ideal natures does not exist. Different dimensionless methods are compared in Table 7. The methods of standardization and extremum treatment are better

$$x_{ki} = \frac{\max(X_i) - X_{ki}}{\max(X_i) - \min(X_i)} \tag{19}$$

In the extremum treatment method, the positive correlation indicators use formula (18) and the negative correlation indicators use formula (19). In these formulas, $i = 1,2,\ldots,7$ and it represents for seven programs. k represents for 13 indicators and $k = 1,2,\ldots,13$. Min and max represent for the maximum and minimum values of each indicator. This method is not applicable for constant indicators. The results of the data processing are as shown in Table 8.

6.2. Weight the indicators based on order relations

The method of order relations is a new method which does not need the consistency test. First, it makes qualitative ranking of the indicators, and then it compares the importance of each pairs of neighboring indicators to determine the final weights. This method makes quantitative calculations according to the subjective preference of the decision-makers. Thus, it is more reliable for the decision-makers and is helpful in practice. In the method of order relations, the indicators should be sequenced qualitatively and be weighted through quantitative calculation without constructing the judgment matrix and consistency test, and without limits for the number of programs. The process is as follows. ① In the set of indicators $\{x_1, x_2, \ldots, x_m\}$, select the most important indicator and record it as x_1^*. In the rest of the indicators $m-1$, choose the most important indicator and record it as x_2^*. Repeat these steps until the only order relations are identified. ② Judge the relative importance of x_{k-1} to x_k. The importance ratio of x_{k-1} and x_k is defined as w_{k-1}/w_k, and $r_k = w_{k-1}/w_k$. The value assignment of r_k is as shown in Table 9. ③ Based on $r_{k-1} > 1/r_k$, the definitions of the weight coefficient are as follows:

$$w_m = \left(1 + \sum_{k=2}^{m} \prod_{i=k}^{m} r_j\right)^{-1} \tag{20}$$

$$w_{k-1} = r_k w_k, k = m-1, \ldots, 2 \tag{21}$$

Based on the dimensionless result, the method of order relations is used to weight the indicators. The results are shown in Table 10.

6.3. Model calculation

According to ELECTRE-II, in the case of macro-site selection, the steps of the comprehensive evaluation are as follows.

(1) Construct the Outranking Relation based on each indicator, as shown in Table 11. The same marked programs represent that the property values of these programs are equal in the certain indicator.
(2) By calculation, the weights of 13 indicators are (0.163, 0.136, 0.058, 0.163, 0.136, 0.097, 0.081, 0.048, 0.029, 0.040, 0.015, 0.012, and 0.024).
(3) Make the concordance test and determine the precedence relation of all the programs. To construct the weak outranking relation, it is necessary to set $\alpha^0 = 0.6$. If $I'_{ik} \geq 1, I_{ik} \geq \alpha^0$ exists, then it passes the concordance test. Qualifying programs and their precedence relations are as shown in Table 12.

Table 9
The value assignment of r_k.

r_k	Explanation
1.0	$x_{k-1}$is as important as x_k's.
1.2	x_{k-1} is a little more important than x_k.
1.4	x_{k-1} is clearly more important than x_k.
1.6	x_{k-1} is mightily more important than x_k.
1.8	x_{k-1} is extremely more important than x_k.

Table 11
The sequencing of seven programs based on the different indicators.

Indicator/sequencing	1	2	3	4	5	6	7
X1	P1	P2	P5	P4	P3	P6	P7
X2	P2=	P5=	P4!	P3!	P1$	P6$	P7
X3	P5	P1	P4	P2	P3	P6=	P7=
X4	P6	P4	P5	P2	P3	P7	P1
X5	P7	P4	P2	P3	P5	P6	P1
X6	P2	P4	P1	P6	P3	P7	P5
X7	P7=	P6=	P4=	P5	P3	P2	P1
X8	P2=	P5=	P4=	P3=	P6=	P7=	P1
X9	P2	P1	P5=	P4=	P3=	P6!	P7!
X10	P4	P1	P5=	P6=	P3	P7	P2
X11	P1=	P2=	P4!	P5!	P6!	P3!	P7
X12	P4=	P3=	P5	P2	P1!	P6!	P7!
X13	P4=	P2=	P1=	P6=	P3!	P5!	P7!

Table 10
The result of weights via order relations.

Indicator	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13
Weight w	0.163	0.136	0.058	0.163	0.136	0.097	0.081	0.048	0.029	0.040	0.015	0.012	0.024

Table 12
Concordance test (weak outranking relation).

p_i	p_k	The sum of those inferior indicators' weights	The sum of those positive indicators' weights	The sum of those negative indicators' weights	Concordance test index I_{ik}	Non-concordance test index I'_{ik}
P2	P1	0.7395	0.7008	0.2605	0.7395	2.6902
P2	P3	0.8668	0.8187	0.1332	0.8668	6.1464
P2	P5	0.6464	0.4626	0.3536	0.6464	1.3082
P2	P6	0.7164	0.6445	0.2836	0.7164	2.2730
P2	P7	0.7436	0.6955	0.2564	0.7436	2.7122
P3	P7	0.7836	0.7117	0.2164	0.7836	3.2892
P4	P1	0.7361	0.7122	0.2639	0.7361	2.6983
P4	P3	1.0000	0.7604	0.0000	1.0000	Infinity
P4	P5	0.6439	0.5523	0.3561	0.6439	1.5512
P4	P6	0.8372	0.6697	0.1628	0.8372	4.1143
P4	P7	0.8644	0.7356	0.1356	0.8644	5.4227
P5	P3	0.7551	0.6396	0.2449	0.7551	2.6114
P5	P6	0.6358	0.5328	0.3642	0.6358	1.4626
P5	P7	0.6867	0.6148	0.3133	0.6867	1.9626
P6	P7	0.7836	0.6369	0.2164	0.7836	2.9432

Table 13
Non-concordance test (weak outranking relation).

p_i	p_k	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13
P2	**P1**	0.252	−0.667	0.072	−0.447	−0.443	−0.347	−0.448	−1.000	−0.250	0.919	0.000	−0.333	0.000
P2	**P3**	−0.460	−0.333	−0.293	−0.008	−0.025	−0.722	0.006	0.000	−0.500	0.676	−0.500	0.667	−1.000
P2	**P5**	−0.054	0.000	0.217	0.121	−0.063	−1.000	0.288	0.000	−0.500	0.81	−0.500	0.333	−1.000
P2	**P6**	−0.469	−0.667	−0.783	0.553	−0.253	−0.676	0.551	0.000	−1.000	0.811	−0.500	−0.333	0.000
P2	**P7**	−0.748	−1.000	−0.783	−0.245	0.557	−0.738	0.552	0.000	−1.000	0.649	−1.000	−0.333	−1.000
P3	**P7**	−0.288	−0.667	−0.491	−0.236	0.582	−0.016	0.546	0.000	−0.500	−0.027	−0.500	−1.000	0.000
P4	**P1**	0.503	−0.333	0.030	−0.659	−0.557	−0.058	−1.000	−1.000	0.250	−0.081	0.500	−1.000	0.000
P4	**P3**	−0.209	0.000	−0.335	−0.220	−0.139	−0.433	−0.545	0.000	0.000	−0.324	0.000	0.000	−1.000
P4	**P5**	0.197	0.333	0.174	−0.091	−0.177	−0.711	−0.263	0.000	0.000	−0.189	0.000	−0.333	−1.000
P4	**P6**	−0.218	−0.333	−0.826	0.341	−0.367	−0.388	0.000	0.000	−0.500	−0.189	0.000	−1.000	0.000
P4	**P7**	−0.497	−0.667	−0.826	−0.457	0.443	−0.449	0.000	0.000	−0.500	−0.351	−0.500	−1.000	−1.000
P5	**P3**	−0.406	−0.333	−0.509	−0.129	0.038	0.278	−0.282	0.000	0.000	−0.135	0.000	0.333	0.000
P5	**P6**	−0.415	−0.667	−1.000	0.432	−0.190	0.324	0.263	0.000	−0.500	0.000	0.000	−0.667	1.000
P5	**P7**	−0.694	−1.000	−1.000	−0.365	0.620	0.262	0.263	0.000	−0.500	−0.162	−0.500	−0.667	0.000
P6	**P7**	−0.279	−0.333	0.000	−0.798	0.810	−0.062	0.000	0.000	0.000	−0.162	−0.500	0.000	−1.000

Table 14
The weak outranking relation.

p_i	p_k	X1	X2	X3	X4	X5	X6	X7	X8	X9	X10	X11	X12	X13
P3	**P7**	−0.288	−0.667	−0.491	−0.236	0.582	−0.016	0.546	0.000	−0.500	−0.027	−0.500	−1.000	0.000
P4	**P1**	0.503	−0.333	0.030	−0.659	−0.557	−0.058	−1.000	−1.000	0.250	−0.081	0.500	−1.000	0.000
P4	**P3**	−0.209	0.000	−0.335	−0.220	−0.139	−0.433	−0.545	0.000	0.000	−0.324	0.000	0.000	−1.000
P4	**P5**	0.197	0.333	0.174	−0.091	−0.177	−0.711	−0.263	0.000	0.000	−0.189	0.000	−0.333	−1.000
P4	**P6**	−0.218	−0.333	−0.826	0.341	−0.367	−0.388	0.000	0.000	−0.500	−0.189	0.000	−1.000	0.000
P4	**P7**	−0.497	−0.667	−0.826	−0.457	0.443	−0.449	0.000	0.000	−0.500	−0.351	−0.500	−1.000	−1.000
P5	**P3**	−0.406	−0.333	−0.509	−0.129	0.038	0.278	−0.282	0.000	0.000	−0.135	0.000	0.333	0.000
P5	**P6**	−0.415	−0.667	−1.000	0.432	−0.190	0.324	0.263	0.000	−0.500	0.000	0.000	−0.667	1.000

(4) Based on Table 12, make the non-concordance test. The principles are as follows. The threshold $d_j, j=1,2,\ldots,13$ of each property should be set by decision makers. For any j, if $y_j(x_k)-y_j(x_i)\ge d_j$, then no matter how large the values of the other properties are, it could not accept the compensation for other properties, namely $x_i o x_k$ are no longer recognized. The results of non-concordance test are as shown in Table 13.

(5) Construct the weak outranking relation. Set $d_j^0=0.6$, then the relations of P2 > P1, P2 > P3, P2 > P5, P2 > P6, P2 > P7, P5 > P7, and P6 > P7 are no longer recognized. Delete these relations and achieve the final result of the precedence relation, as shown in Table 14.

(6) Similarly, construct the strong outranking relation. Set $\alpha=0.7$ and $d_j^*=0.95$. Select the precedence relation of the programs which meet $0.6\le d_j\le 0.95$, and the tables of concordance test, non-concordance test and the strong outranking relation could be gained.

(7) Construct points-to graphs. Construct the strong points-to graph and the weak points-to graph based on the strong Outranking Relation o_s and the weak Outranking Relation o_w, shown as in Fig. 1 (a) and (b). Based on ELECRTE-II, the value of positive sorting $V'(p_i)$, negative sorting $V^0(p_i)$ and the final sorting $\overline{V}(p_i)$ could be achieved as shown in Table 15.

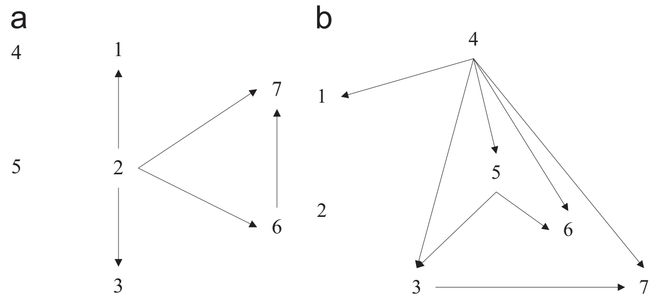

Fig. 1. (a) The strong points-to graph. (b) The weak points-to graph.

Table 15
The result of the evaluation based on ELECRTE-II.

Items	P1	P2	P3	P4	P5	P6	P7
$V'(p_i)$	2	1	3	1	2	3	4
$V^0(p_i)$	1	3	1	4	3	2	1
$V''(p_i)$	4	2	4	1	2	3	4
$\overline{V}(p_i)$	3	1.5	3.5	1	2	3	4

6.4. Result analysis

According to the results in Table 15, it can be indicated that the final ranking of seven wind/solar hybrid power stations is $P_4 mac; sc; P_2 mac; sc; P_5 mac; sc; P_1 = P_6 mac; sc; P_3 mac; sc; P_7$.

First of all, Naqu Prefecture in Tibet (P_7) is recognized to be the worst one in the evaluation. From the perspective of natural resources, the region has better solar energy resources, but the conditions of wind resource are ordinary, and the technology of wind power generation in high altitude still needs more further study. This region is away from the load centers, lack of electricity demand and has bad traffic conditions. However, power construction is likely to cause damage to the environment. Therefore, at this stage, Naqu Prefecture is not appropriate to develop large-scale hybrid power station of wind/solar.

The resource conditions of Youyu (P_3) is similar to Naqu Prefecture's. Due to the unique terrain of this region which is in the vent position, its wind energy conditions are good, but it has short of electricity demand and traffic conditions. The station construction is likely to cause damage to the environment. Therefore, Youyu is appropriate to give priority to the development of wind power generation and secondly consider developing large-scale photovoltaic power generation according to the policy conditions in the future.

The development conditions of wind/solar hybrid power station in Shantou (P_1) and Haixi (P_6) are similar. But each region has its own characteristics. Shantou is in the strip zone with strong wind, and the wind energy conditions are better. However, because of the effects of oceanic climate, solar energy conditions are not particularly stable and the unit of photovoltaic power generation is generally small. Since extreme weather such as typhoons occurs frequently, the operation and maintenance costs of wind power station are much higher than other regions. In contrast, solar conditions of Haixi are excellent. Relatively speaking, the wind conditions are ordinary. Therefore, Haixi is more suited to give priority to the development of photovoltaic power generation, and develop the wind power generation secondly.

In the evaluated regions, Erlian haote (P_4), Zhangjiakou (P_2) and Yumen (P_5) are very suitable for constructing the wind/solar hybrid power station. These three regions have good conditions of wind energy, solar resources and the complementary strengths of resources. They are located in smooth plain and have good construction conditions. The extension of the electricity grid helps to facilitate large-scale electric power transmission. Therefore, these regions are the most suitable for the development of wind/solar hybrid power station.

6.5. Result validation

The paper which is named macro-site selection of wind/solar hybrid power station based on the Ideal Matter-Element Model by Yunna Wu only analyzed the advantages and disadvantages of three regions named Inner Mongolia, the middle of Qinghai and East of Tibet merits which are recorded as P_4, P_6, and P_7 in the paper [12]. The result described in paper [12] is the same with the conclusion of this paper, which verifies the correctness of this method. The method of ELECTRE-II has two main advantages. First, it is easier for decision-makers to understand the principle of the method. So they are willing to use it and undertake the corresponding responsibilities in the decision-making process. Second, the calculation is not complicated and can be programmed once the weights, α and d_j, are set based on the characteristics of the problem and the data in the decision-making matrix by policy makers. Compared with the ranking methods based on relative position, ELECTRE-II uses the information in the decision-making matrix and carries out the concordance test and non-concordance test. Thereby, the sorting result is more effective. Furthermore, when communicating with the decision-makers, most of them express that the calculation procedures of the ELECTRE-II method are logical and clear, and the results are consistent with the fact. Therefore, this method has been more widely used.

7. Conclusions

This paper aims to study macro-site selection of wind/solar hybrid power station. First, the framework of the indicator system is obtained from the literature review. Then according to the different perspectives of various scholars and the relevance of the indicators, the indicator system is refined in order to get a more scientific and effective evaluation system. As a method of comprehensive evaluation, ELECTRE-II is intelligible and could bear the responsibility for decision-making in the evaluation process. What is more, the process of the calculation is not complicated and difficult to understand, and very easy to program. Finally, this paper selects seven wind/solar hybrid power stations which have been put into operation as the case study, weights the indicators by the method of order relations, and evaluates these seven regions via ELECTRE-II. The conclusions are as follows: Erlian haote (P_4), Zhangjiakou (P_2) and Yumen (P_5) are the best. Shantou (P_1) and Haixi (P_6) are the second. Youyu (P_3) and Naqu (P_7) are the worst. The result is consistent with the related research findings and has better correctness. This paper could provide some theoretical basis for the macro-site selection of wind/solar hybrid power station.

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References

[1] Yin J, Zhang QF. Analysis of wind-solar hybrid generating system. World Invert 2008;75(8):43–5.
[2] Yoreley CS, Antonio JGT, Jorge XB. Analytical methods for wind persistence: their application in assessing the best site for a wind farm in the State of Veracruz, Mexico. Renew Energy 2010;35:2844–52.
[3] Hang JM, Duan D, Wang C. Wind farm site selection and feasibility study in Yueyang. In: Proceedings of the international conference on Chinese meteorological society; 2005, p. 35–41.
[4] Li ZR, Hong ZL. The problems discussing of Yunnan power grid absorb large capacity of wind power. Yunnan Power Technol. Proc. 2009:10–31.
[5] Amy HIL, Hsing HC, He YK. Multi-criteria decision making on strategic selection of wind farms. Renew Energy 2009;34(1):120–6.
[6] Rob VH, Vasilis F. GIS-based wind farm site selection using spatial multi-criteria analysis (SMCA): evaluating the case for New York State. Renew Sustain Energy Rev 2011;15(7):3332–40.
[7] Shimy MEL. Optimal site matching of wind turbine generator: case study of the Gulf of Suez region in Egypt. Renew Energy 2010;35(8):1870–8.
[8] Qian XZ, Cui XL. The modeling study of choicing wind farm. Meteorol Sin 1995;4:495–503.
[9] Mao SY, Xu WN, Hou YM, Zhu LQ, Zhang C. Discussion on site selection of solar photovoltaic power station. J China Three Gorges Univ 2011;4:26–30.
[10] Ma YG, Zhang Y, Zeng L. Site selection for off-grid PV power stations in mountains and valleys. Sol Renew Energy Sources 2008;4:30–1.
[11] Aras Haydar, Erdogmus Senol, Koc Eylem. Multi-criteria selection for a wind observation station location using analytic hierarchy process. Renew Energy 2004;29:1383–92.
[12] Wu YN, Yang YS, Feng TT, et al. Macro-site selection of wind/solar hybrid power station based on Ideal Matter-Element Model. Int J Electr Power Energy Syst 2013;50:76–84.
[13] Yun LP. The study of site optimization for wind farm basing on fuzzy synthesis evaluation. North China Electr Power Univ 2008:23–38.
[14] Deng YC, Yu Z. Methodology of wind resource assessment in wind farm macro-siting based on reference wind turbine. Energiae Sol Sin 2010;11:1516–20.
[15] Li QW. Micro-setting and wind power research of Da Tang Ji Lin Xiang Yang. Jilin: Jilin University; 2011; 24–36.